

The MEASUREs PAR Project

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Objective

- To produce a 12-year (and continuing) time series of daily PAR at the ocean surface from SeaWiFS, MODIS-Terra, and MODIS-Aqua for biogeochemistry applications.
- The product will cover the global oceans, with a spatial resolution of about 9.3x9.3 km (equal area grid), the resolution of Level 3 ocean-color products from those sensors.
- The time series will start in September 1997, i.e., at the beginning of the SeaWiFS operational phase.

Definition

-PAR is defined as the quantum energy flux from the Sun in the spectral range 400-700 nm. It is expressed in Einstein/m²/day. Daily PAR is the average flux during a day (24 hours).

Importance

-PAR controls the growth of phytoplankton and, therefore, the development of crustaceans, fish, and other consumers.

-It ultimately regulates the composition and evolution of marine ecosystems.

-Knowing the distribution of PAR over the oceans, spatially and temporally, is critical to:

- Understanding bio-geo-chemical cycles of carbon, nutrients, and oxygen, and
- Addressing climate and global change issues, such as the fate of anthropogenic atmospheric carbon dioxide.

Satellite Estimation

- PAR is computed as the difference between the 400-700 nm solar flux incident on the top of the atmosphere (known) and reflected back to space by the atmosphere and surface (measured), taking into account atmospheric absorption (modeled).
- Knowledge of pixel composition is not required, eliminating the need for cloud screening and arbitrary assumptions about sub-pixel cloudiness.

Model

-The PAR model uses plane-parallel theory and assumes that the effects of clouds and clear atmosphere can be de-coupled. The planetary atmosphere is therefore modeled as a clear sky atmosphere positioned above a cloud layer.

-The solar flux reaching the ocean surface is given by

$$E = E_{\text{clear}}(1 - A)(1 - A_s)^{-1}$$

where A is the albedo of the cloud-surface system and A_s the albedo of the surface.

$-E_{\text{clear}} = E_0 \cos(\theta_s) T_d$ T_g is the solar flux that would reach the surface if the cloud/surface system were non reflecting and non-absorbing.

-In clear sky conditions, A reduces to A_s .

Algorithm

-In order to compute E , A is expressed as a function of the radiance measured by the ocean-color sensor in the PAR spectral range. This includes:

- (1) converting the TOA radiance into reflectance,
- (2) correcting the TOA reflectance for gaseous absorption and scattering by the atmosphere/surface system, and
- (3) transforming the corrected reflectance into albedo.

Procedure No. 1:

- A daily PAR estimate is obtained for each instantaneous pixel, assuming the cloud/surface system is stable during the day and corresponds to the satellite observation.
- Daily PAR estimates obtained separately from different orbits and individual sensors are binned using a simple, linear averaging scheme (arithmetical mean), or by weighting the estimates using the cosine of the solar zenith angle.

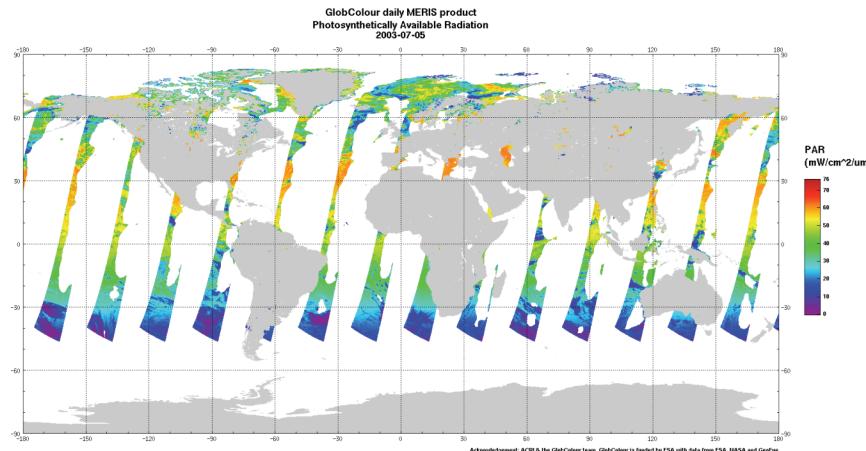
Procedure No. 2:

- The Level 1b data from each sensor is processed individually, as in the first procedure, but up to the albedo of the cloud-surface system A .
- The daily fields of A and associated sun zenith angle, obtained for each orbit of each satellite, are used to perform daily integration and generate the Level 3 binned PAR product.

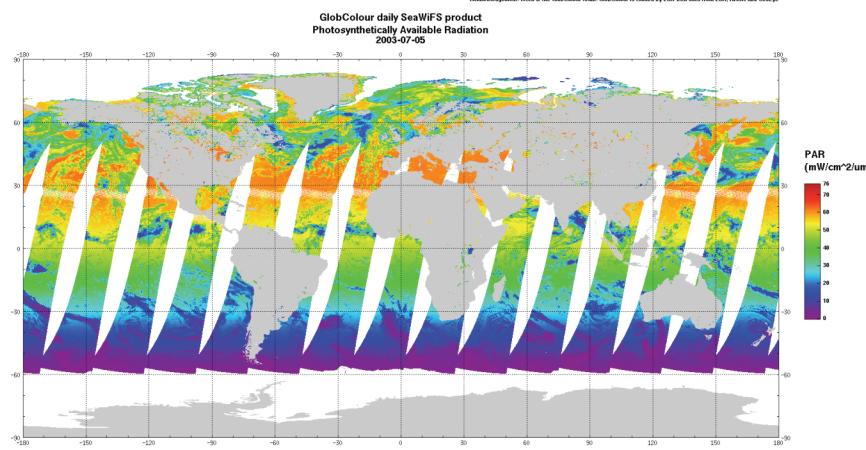
- Since MODIS-Terra, SeaWiFS, and MODIS-Aqua cross the Equator at different local times (i.e., 10:30, 12:00, and 13:30) the diurnal variability of clouds is taken into account by averaging individual estimates (Procedure No. 1).
- Procedure No. 2 is preferred, since the multiple sensor data, obtained at different times during the day, are used in the daily integration of instantaneous PAR.
- To ensure consistency of the PAR data over time, estimates using data from one, two, or three sensors need to be compared, and statistical adjustment factors determined.
- Procedure No. 1 has been used to generate the operational SeaWiFS PAR product. It has been adapted to POLDER, GLI, MODIS, and MERIS. It has been applied by the GlobColour project to create a merged MERIS/SeaWiFS PAR product.

Daily PAR

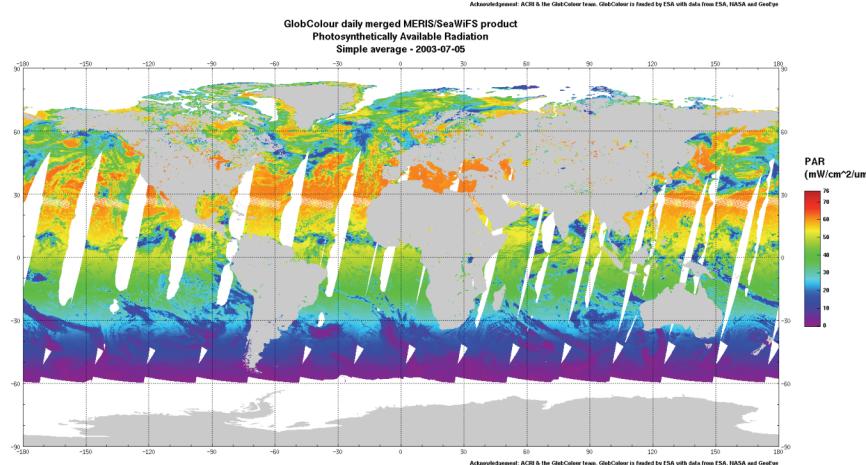
05 July 2003



MERIS



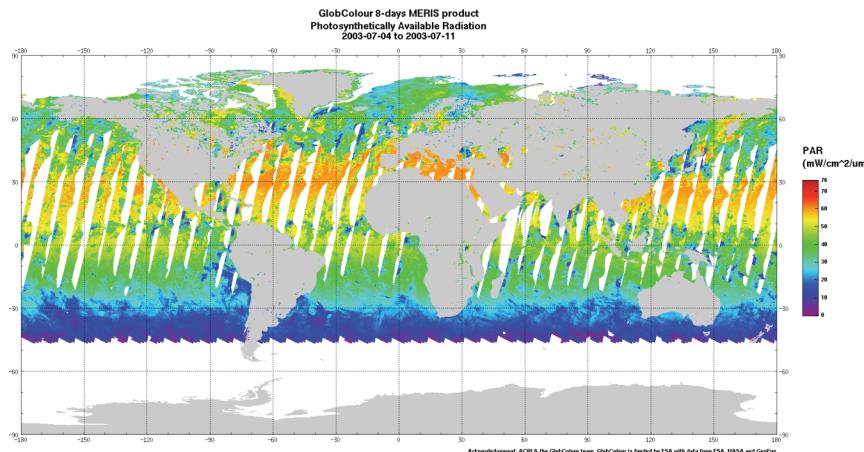
SeaWiFS



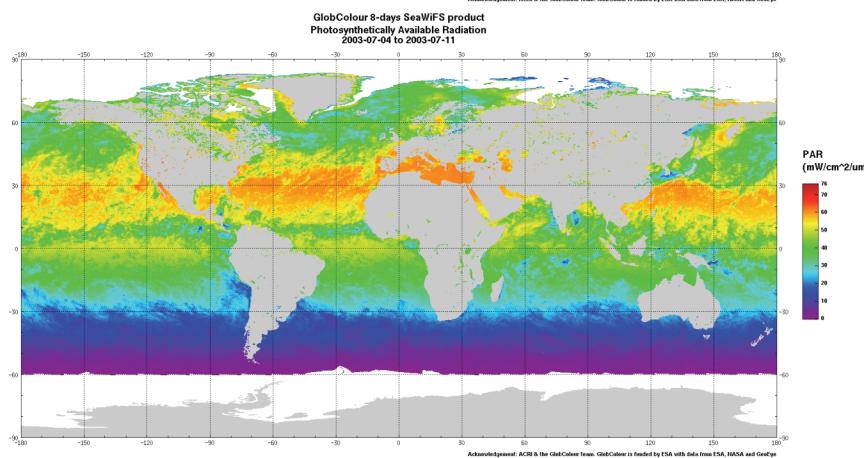
Merged
MERIS/
SeaWiFS

8-Day PAR

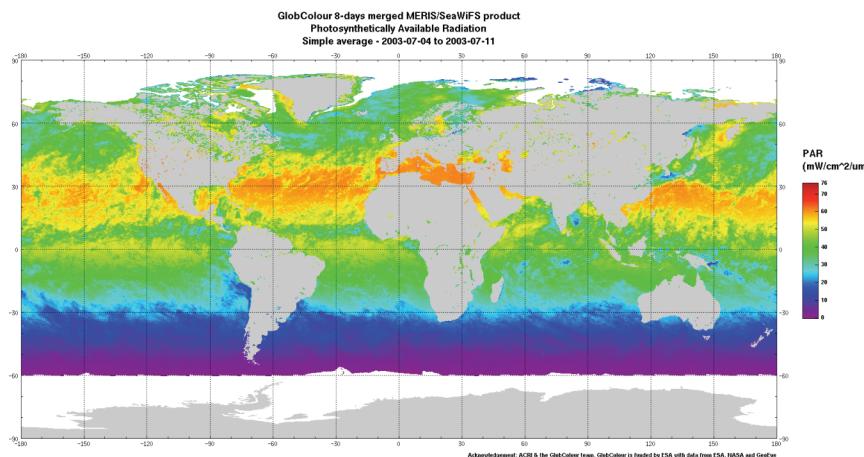
04-11 July 2003



MERIS



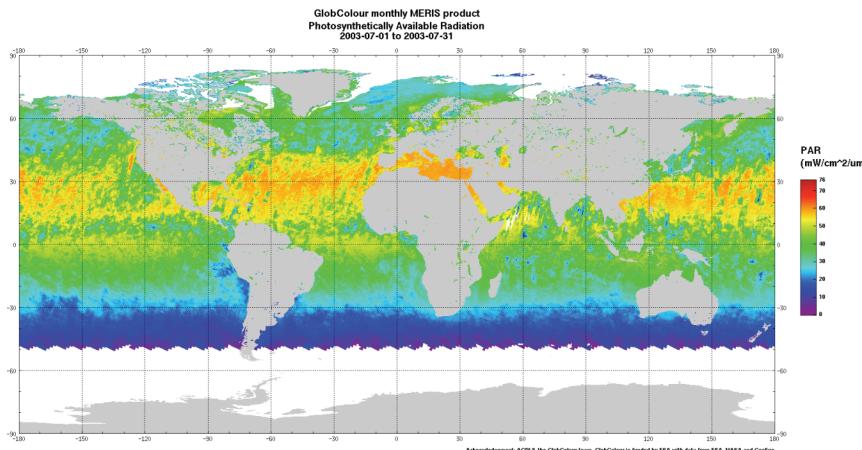
SeaWiFS



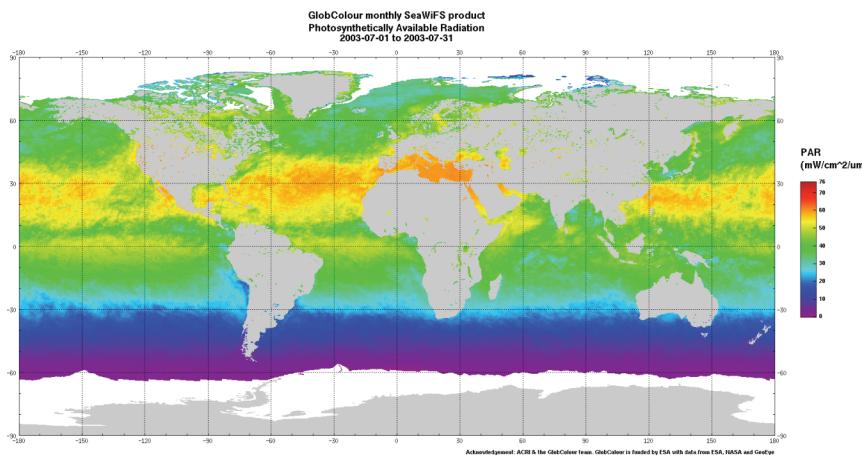
Merged
MERIS/
SeaWiFS

Monthly PAR

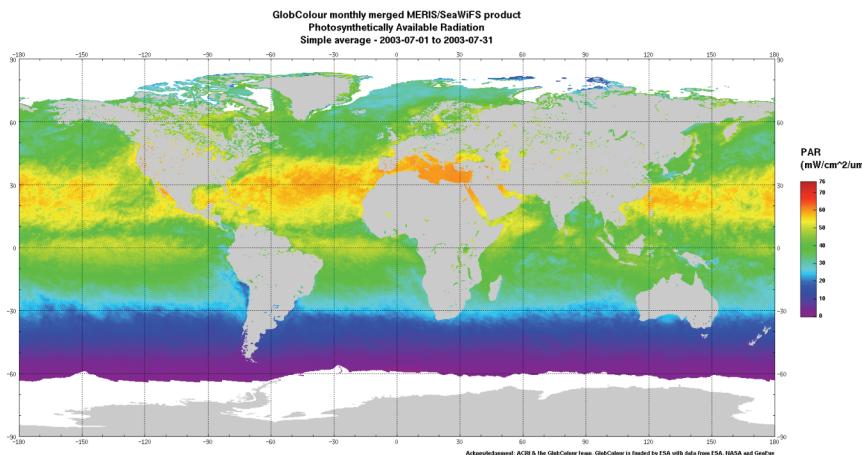
July 2003



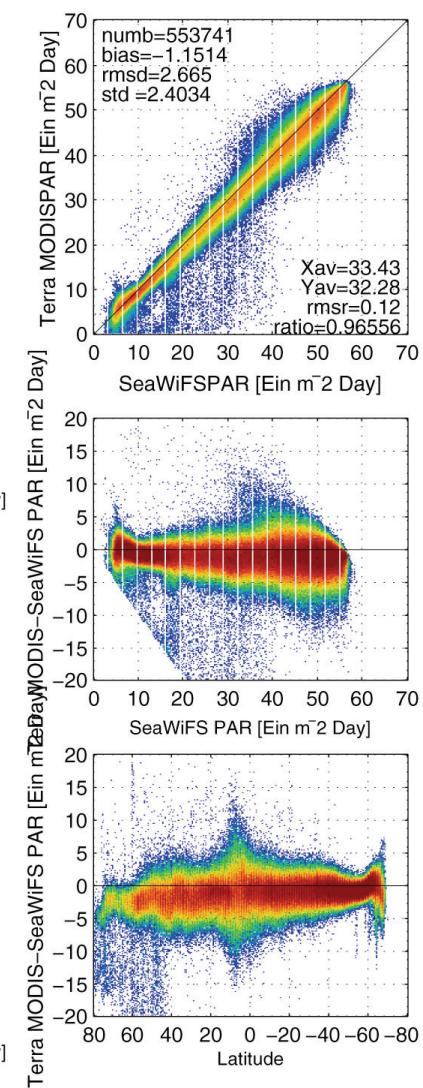
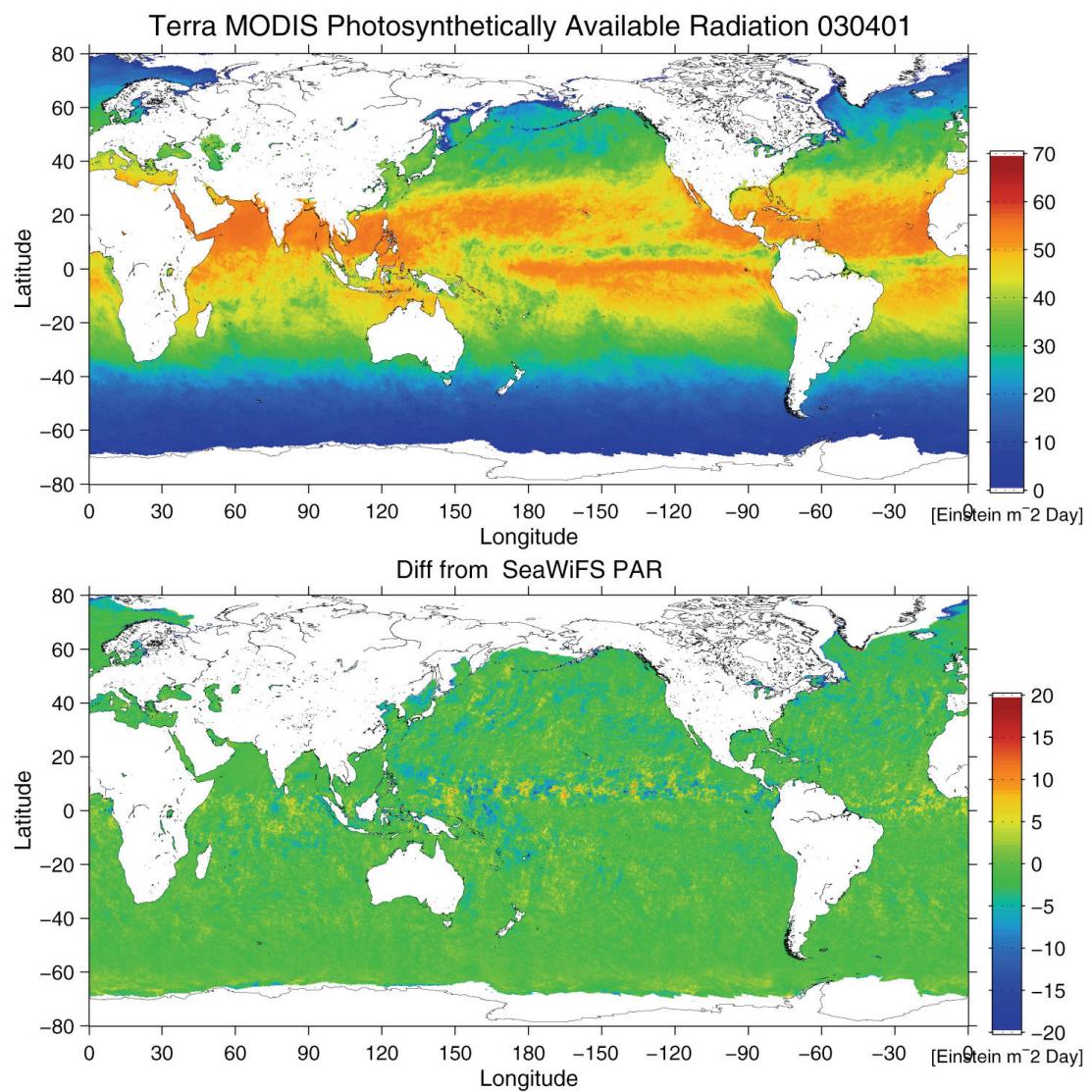
MERIS



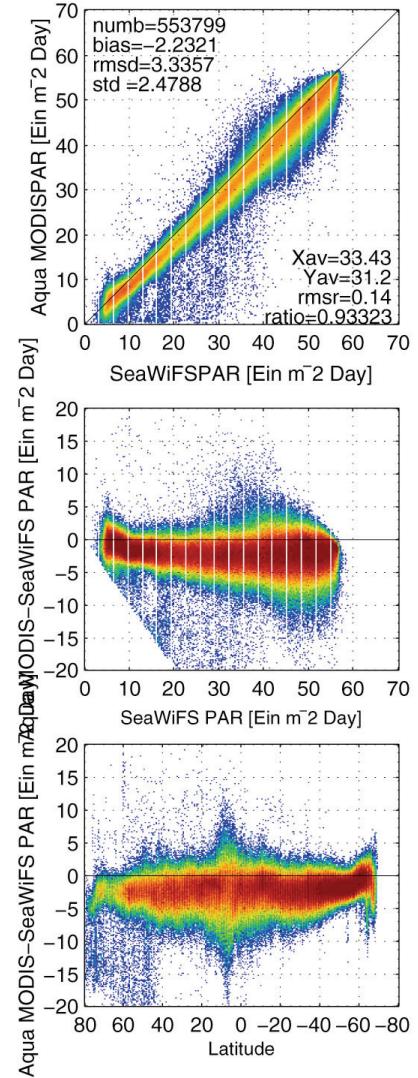
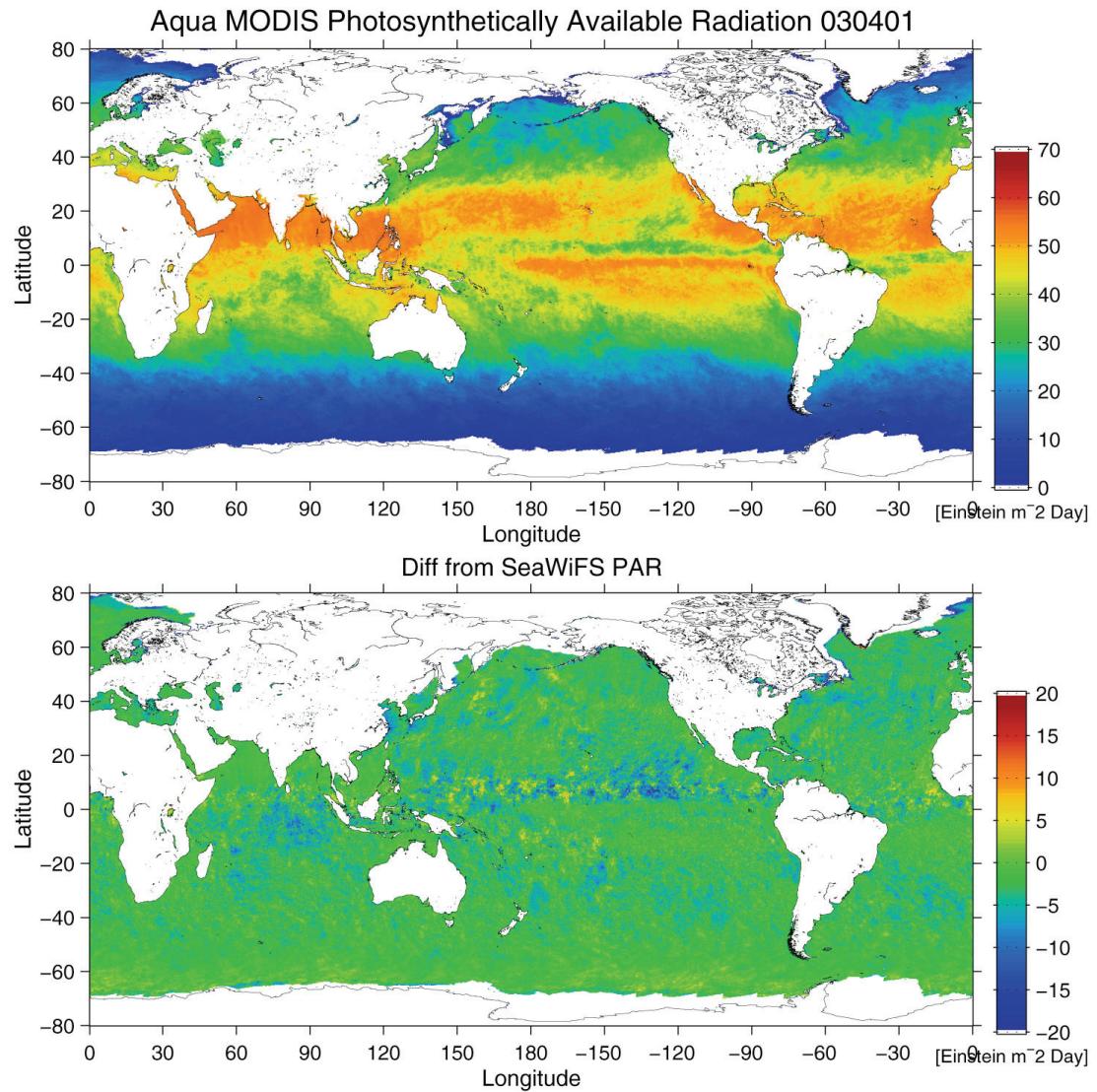
SeaWiFS



Merged
MERIS/
SeaWiFS



Comparison of MODIS-Terra PAR estimates with SeaWiFS PAR estimates for April 2003 (monthly average).



Comparison of MODIS-Aqua PAR estimates with SeaWiFS PAR estimates for April 2003 (monthly average).

Status

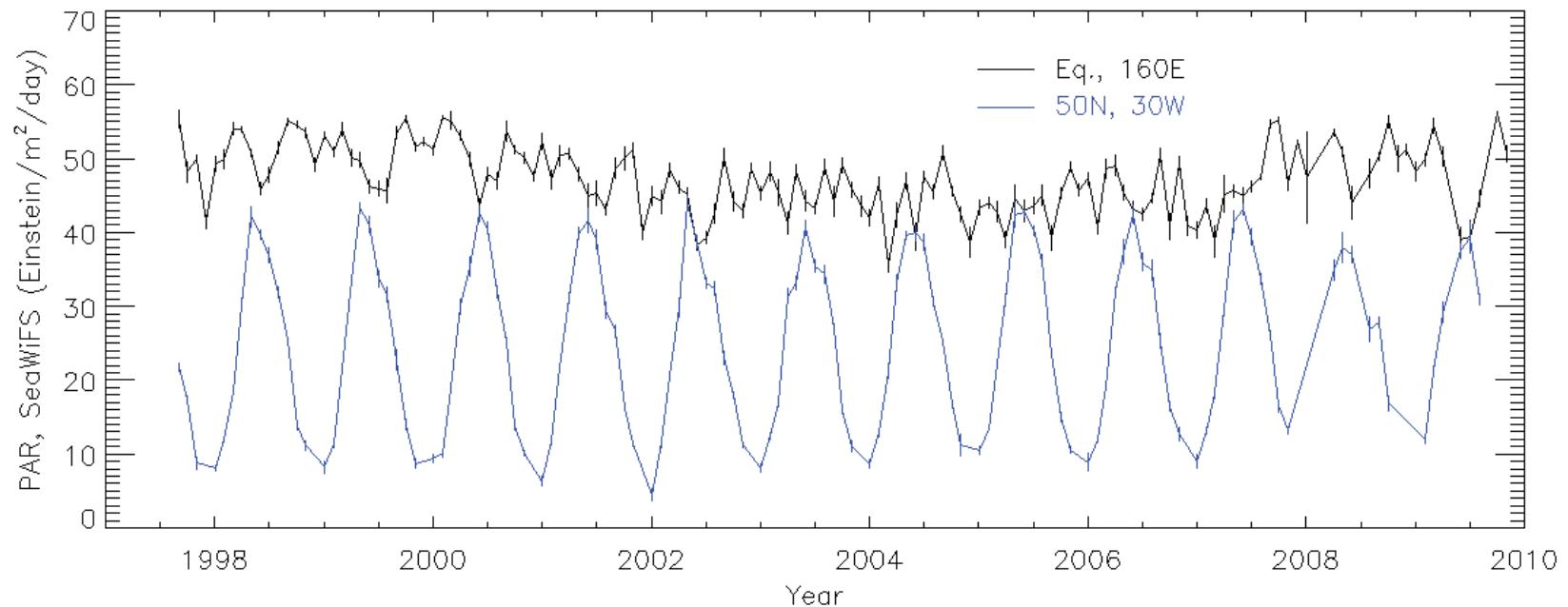
-SeaWiFS PAR code has been modified:

- To fix minor bugs in the computation of ozone transmittance and spherical albedo of the atmosphere.
- To test for missing aerosol optical thickness and Angström coefficient.
- To account dynamically for sea ice using NSIDC daily products at 25x25 km resolution.

-SeaWiFS data re-processed for PAR by NASA OBPG using modified code (task completed November 10, 2009).

-SeaWiFS PAR code has been adapted to MODIS-A and MODIS-T and delivered to NASA OBPG in November 2009. First PAR maps have been generated.

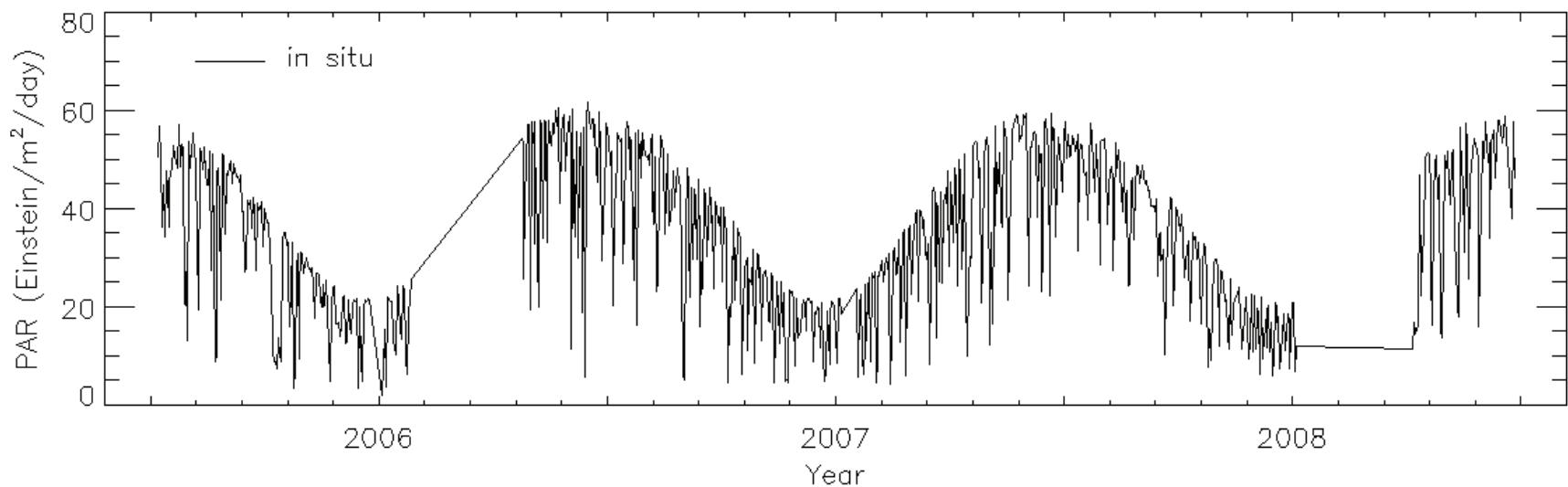
Long-term time series



Time series of SeaWiFS-derived monthly surface PAR at selected locations in the Western Pacific and North Atlantic. Spatial resolution is about 37 km.

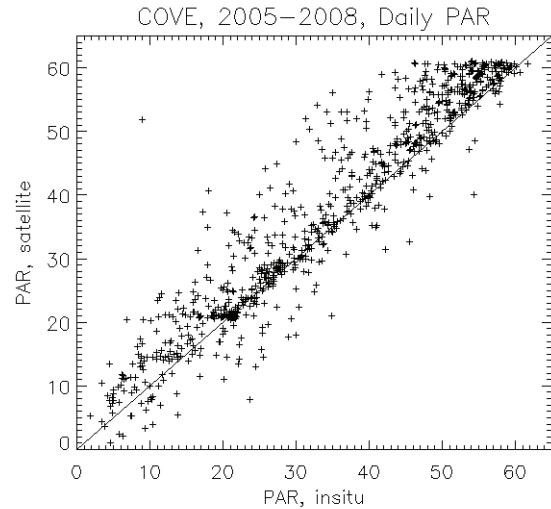
Evaluation

-The SeaWiFS PAR algorithm/product has been evaluated against in situ measurements from the COVE platform off the west coast of the US (2 PAR sensors, 36.90N-75.71W)

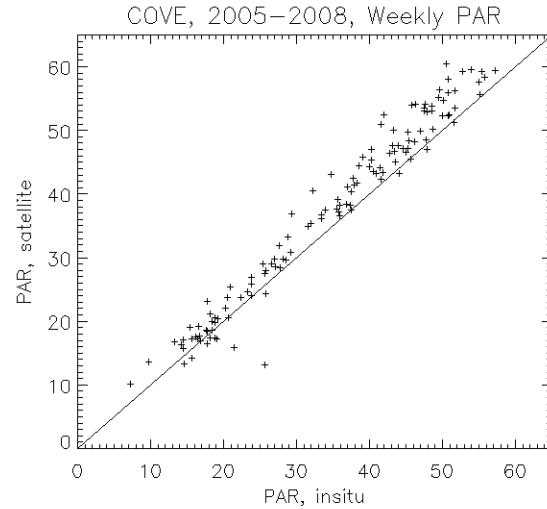


Time series of daily surface PAR measured in situ (average of data from 2 PAR sensors) at the COVE site.

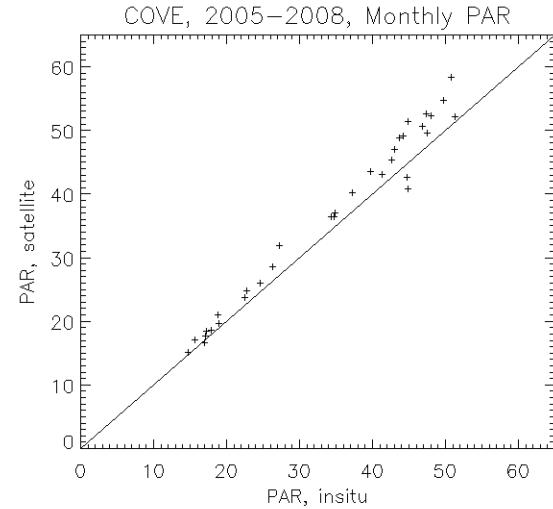
Satellite/*In Situ* comparison



$r^2 = 0.902$
Bias = 3.04 E/m²/d (8.8%)
RMS Diff. = 5.98 E/m²/d (17.3%)
Nb. Points = 847



$r^2 = 0.964$
Bias = 2.75 E/m²/d (8.0%)
RMS Diff. = 4.01 E/m²/d (11.7%)
Nb. Points = 130



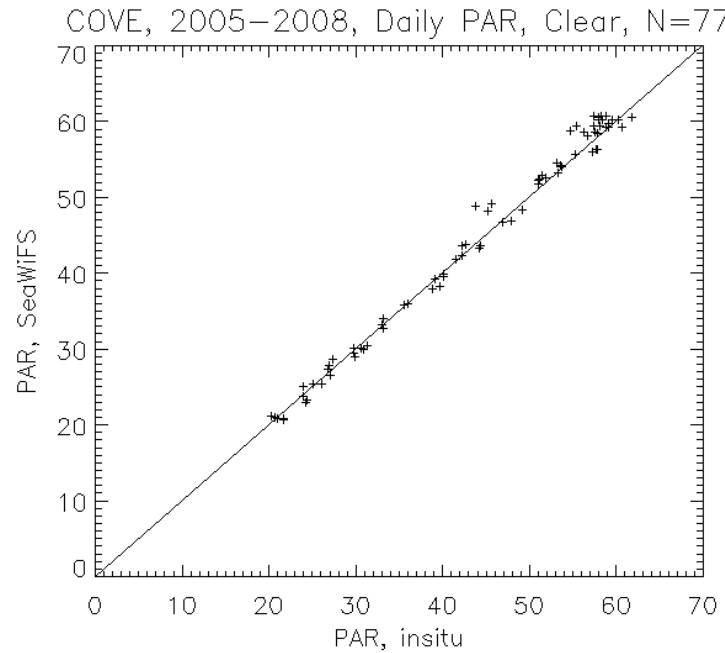
$r^2 = 0.976$
Bias = 2.41 E/m²/d (7.0%)
RMS Diff. = 3.35 E/m²/d (9.8%)
Nb. Points = 33

Comparison of SeaWiFS-derived surface PAR with in situ measurements on daily (left), weekly (center), and monthly (right) time scales at the COVE site.

The bias between satellite PAR estimates and *in situ* measurements may be due to uncertainties in the modeling and/or effects of diurnal cloud variability.

- Clear sky PAR values agree well with those from accurate and validated RT code and with *in situ* measurements, i.e., the bias is not explained by the modeling of clear sky PAR.
- In cloudy conditions, SeaWiFS observations tend to occur at noon or in early afternoon, i.e., when cloudiness is reduced, explaining higher satellite estimates.
- Bias is expected to be significantly reduced by including observations from MODIS-Terra (10:30am) and MODIS-Aqua (1:30pm).

Clear sky estimates

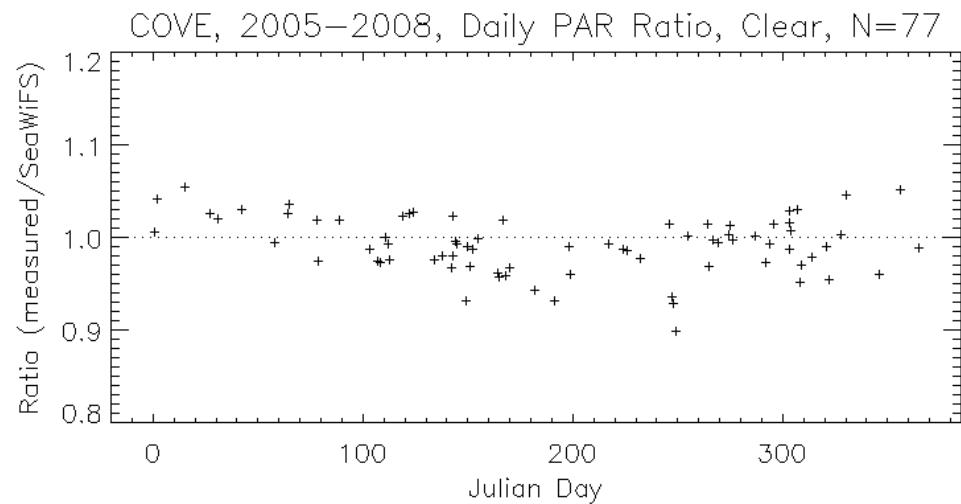


$r^2 = 0.991$

Bias = 0.53 E/m²/d (1.2%)

RMS Diff. = 1.50 E/m²/d (3.4%)

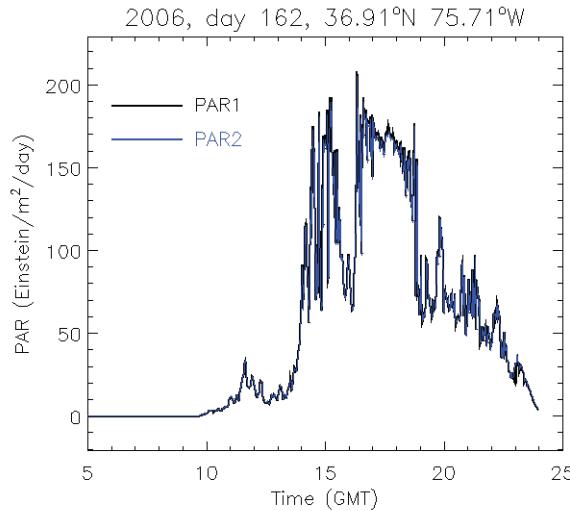
Nb. Points = 77



Mean ratio (Measured/SeaWiFS): $0.99 \pm 0.03(1\sigma)$

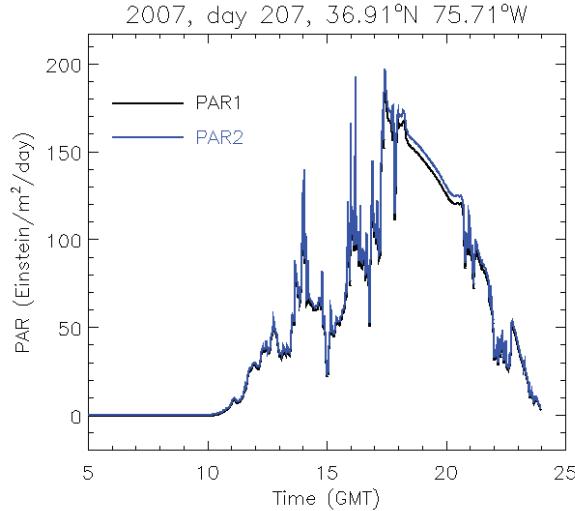
Comparison of SeaWiFS daily surface PAR (clear sky) with in situ measurements at the COVE site.

Typical cloudy situations



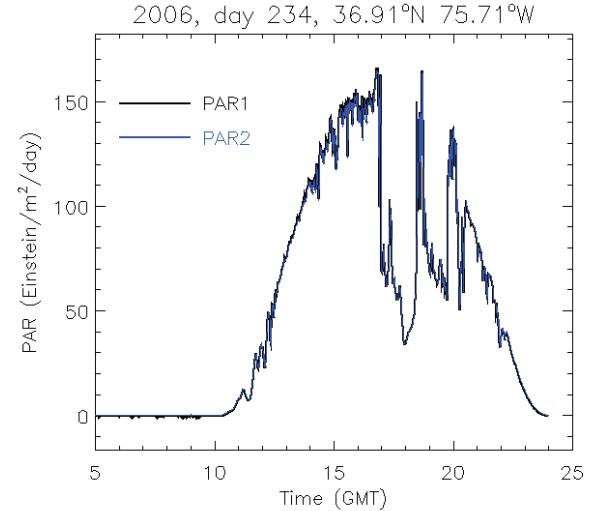
MODIS-T: 16.25 GMT
MODIS-A: 17.83 GMT
SeaWiFS: 18.19 GMT

PAR (in situ): 41.7 $\text{E}/\text{m}^2/\text{d}$
PAR (SeaWiFS): 58.9 $\text{E}/\text{m}^2/\text{d}$
PAR (MODIS-T, MODIS-A,
SeaWiFS): 53.6 $\text{E}/\text{m}^2/\text{d}$



MODIS-T: 15.25, 16.83 GMT
SeaWiFS: 18.34 GMT
MODIS-A: 18.50 GMT

PAR (in situ): 43.53 $\text{E}/\text{m}^2/\text{d}$
PAR (SeaWiFS): 56.87 $\text{E}/\text{m}^2/\text{d}$
PAR (MODIS-T, MODIS-A,
SeaWiFS): 41.28 $\text{E}/\text{m}^2/\text{d}$



MODIS-T: 15.42 GMT
MODIS-A: 18.67 GMT
SeaWiFS: 19.13 GMT

PAR (in situ): 40.9 $\text{E}/\text{m}^2/\text{d}$
PAR (SeaWiFS): 34.9 $\text{E}/\text{m}^2/\text{d}$
PAR (MODIS-T, MODIS-A,
SeaWiFS): 42.4 $\text{E}/\text{m}^2/\text{d}$

-Significant improvement by combining daily estimates from MODIS-T, MODIS-A, and SeaWiFS.

Future Work

- Continue to test current version of PAR code against in situ measurements (COVE and BOUSSOLE sites). This using SeaWiFS, MODIS, and combined estimates. Understand biases, and make eventual adjustments.
- Generate a first 12-year time series of daily PAR using one, two, or three sensors.
- Determine adjustment factors, by comparing estimates with one, two, or three sensors. Generate a second time series.